Kuroshio Penetrations into the South China Sea: Analysis of the Dynamics and Predictability

Vitalii Sheremet, Mail Stop 21
Department of Physical Oceanography
Woods Hole Oceanographic Institution
Woods Hole, MA 02543.
Tel: 508-289-2717 Fax: 508-457-2181 E-mail: vsheremet@whoi.edu

Grant Number: N00014-02-1-0472

LONG-TERM GOALS

Our ultimate goals are to understand the dynamics of the Kuroshio penetrations into the South China Sea and to develop a model of its predictability on interannual and seasonal time scales.

OBJECTIVES

Our objectives are:

1. To identify the main dynamical mechanism responsible for the Kuroshio penetrations into the South China Sea as a loop current,

2. To study the relationship between the loop current penetrations and external factors such as transport and speed of the Kuroshio outside the Luzon Strait, wind stress, and also velocities induced by excited basin Rossby modes.

3. To search for evidence of multiple quasi-steady circulation states and hysteresis in the loop current evolution, which will lay a basis for a predictability model of the loop current penetrations on seasonal and interannual time scales using a dynamical system approach.

APPROACH

Our hypothesis is that the Kuroshio usually leaps across the Luzon Strait; however, during periods when its strength is substantially reduced, it may penetrate into the South China Sea due to the beta effect (Sheremet, 2001). More importantly the flow can be in multiple quasi-steady states and the transition between them involves a hysteresis (dependence on prior evolution). We have been testing this hypothesis with a combination of (1) a theoretical analysis of the flow dynamics in the Luzon Strait, (2) an analysis of historical observations of the Kuroshio, and (3) an analysis of the output in the North Pacific Ocean Nowcast/Forecast System (NPACNFS) and Navy Layered Ocean Model (NLOM) developed at the Naval Research Laboratory at Stennis Space Center, focusing on the area near the Luzon Strait and on the northern part of the South China Sea.

WORK COMPLETED

During this phase of the project we focused on the seasonal variation of the Kuroshio penetrations into the South China Sea. We analyzed the outputs of the NPACNFS model covering the time from 1999 to present, and of the NLOM model running in a hindcast mode from 1993 through 2000, which assimilate satellite information. We looked for the relationships between intrusions and exteranal forcings such as the wind stress obtained from the ECMWF reanalysis covering a period from 1957 through 2002, the Kuroshio transport and dynamic height fluctuations outside the Luzon Strait. We used the observational data from the NODC archive (T, S, dynamic height), High Resolution XBT network (HRX, Gilson and Roemmich, 2002), and drifters (Centurioni *et al.,* 2003). The findings were compared with the prediction of our theoretical model (Sheremet, 2001) and with a more advanced model incorporating realistic coastline and stratification. To suppress short time scale variability we employed the method of relaxation to a running mean (Sheremet, 2002).

We also collaborated with T. Duda, D.-S. Ko, S. Ramp on the effect of the Kuroshio penetrations on propagation of internal solitons generated in the Luzon Strait and observed during ASIAEX.

The results of this research have been presented at the European Geophysical Union General Assembly (Sheremet, 2003a), at the American Meteorological Society Meeting (see conference paper Sheremet, 2003b), and at a number of seminars.

RESULTS

Based on our analysis of historic hydrographic observations it was found that the most dominant seasonal signal, which is associated with the Kuroshio penetrations, is found west of Taiwan from November through February at 150m depth (see Figure 1). This level is below the seasonal mixed layer and still within the dynamical influence of the Kuroshio current. The seasonal variation of the temperature at a characteristic point west of Taiwan shows an abnormal warming during winter months despite some general cooling of the Kuroshio waters (Figure 1, bottom panel).

We extended the study of Metzger and Hurlburt (2001) and considered in more detail individual penetrations events, which revealed that there are two different kinds of events: the summer penetrations following the southern pathway into the South China Sea, they are less predictable, are often associated with ring shedding, and appear to be connected with the decreased transport of Kuroshio outside of the Luzon Strait as suggested by the NPACNFS data. The winter penetrations follow the northern pathway along the west coast of Taiwan, they are clearly caused by the northeast monsoon and the associated Ekman transport in agreement with (Farris and Wimbush, 1996). The two pathways can be easily differentiated by the latitude of the loop current turning point, which is shown in Figure 2 along with two corresponding typical flow patterns and with the seasonal variation of the wind stress. We find that a sharp transition from one mode to another occurs around May after the northeast monsoon ends, this explains very different circulation conditions observed during the two ASIAEX field surveys conducted in spring of 2000 and 2001. We find the drifter observations (Centurioni *et al.,* 2003) to be in very good agreement with our seasonal timing based on historic hydrographic measurements, wind stress variability and the output of the numerical models.

IMPACT/APPLICATIONS

Our results are helping in the interpretation of hydrographic observations of the jet impinging on the shelf in the Northern South China Sea during ASIAEX. They are also relevant to other areas where the boundary current penetrates into a marginal basin as in the Gulf of Mexico, or in the Gulf of Maine.

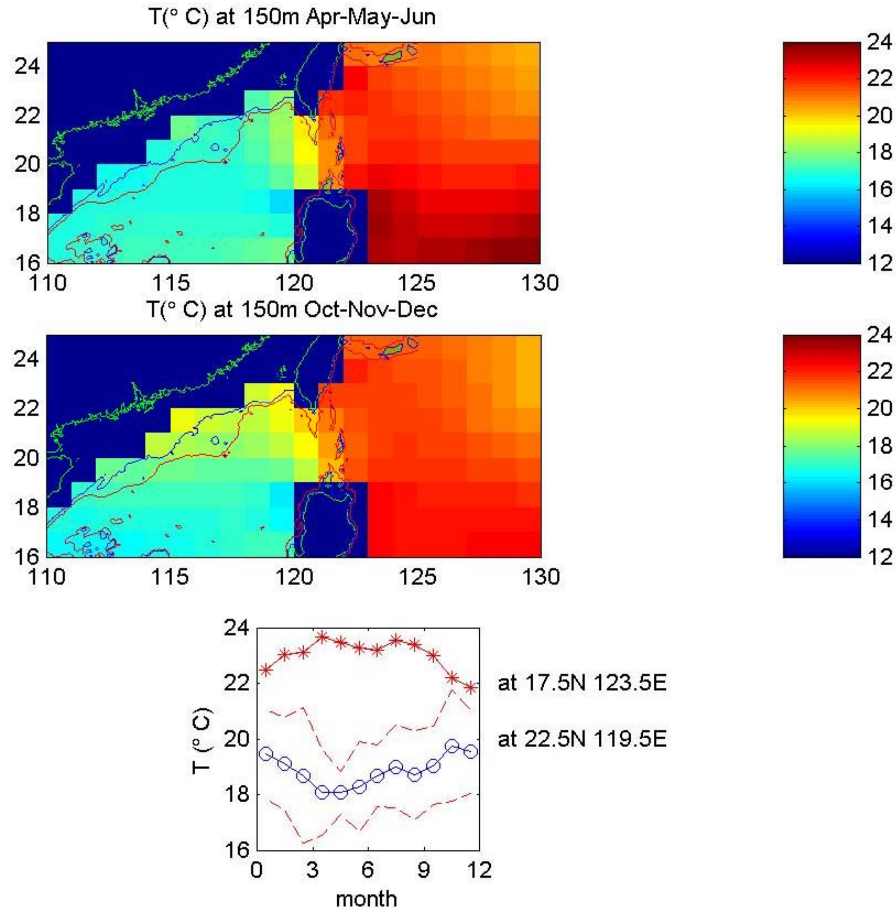

Figure 1: The distribution of the seasonally averaged temperature at 150m depth around the Luzon Strait: the spring season Apr-May-Jun (upper panel); the fall season Oct-Nov-Dec (middle panel). The coastline, 200m and 1000m bathymetric contours are shown. The seasonal variation of temperature at 150m (lower panel) averaged over a 1x1 degree square at two characteristic locations: at 17.5N 123.5E outside the South China Sea (red curve and stars) and at 22.5N 119.5E inside the South China Sea just west of Taiwan (blue curve and circles). Dashed curves indicate the standard deviation. The data are from the World Ocean Atlas 2001, National Oceanographic Data Center.

TRANSITIONS

We are actively communicating the results with Glen Gawarkiewicz, Tim Duda (WHOI), and D. Ko (NRL, Stennis Space Center) to help interpret observations during ASIAEX and to diagnose the output of the NPACNFS. We also discuss the results with John Gilson and Dean Roemmich (maintaining HRX network) as well as with Luca Centurioni and Peter Niiler (Scripps) conducting a current drifter release project (supported by ONR) around the Luzon Strait.

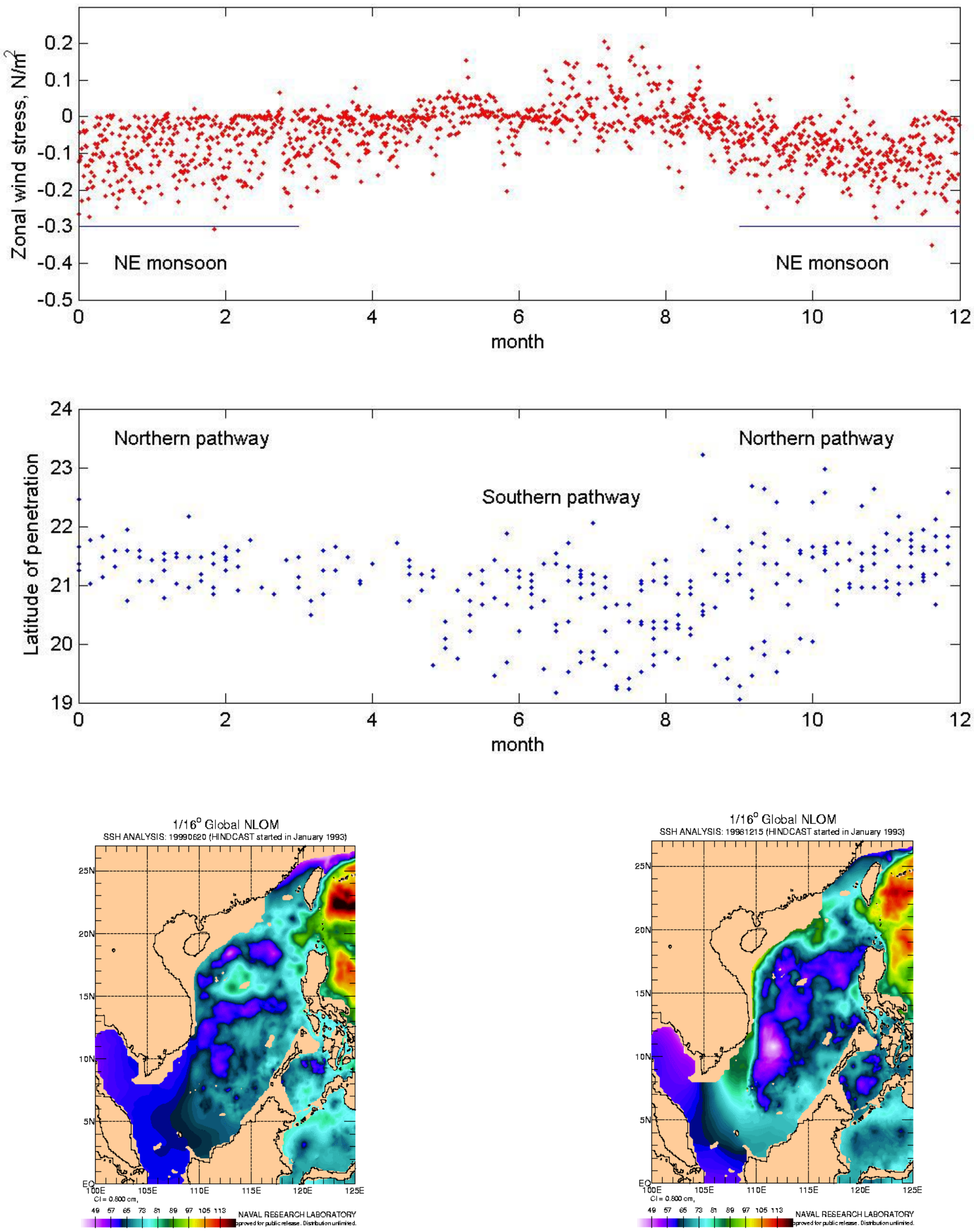

Figure 2: The ECMWF reanalysis zonal wind stress (during 1994-2000) at a representative location in the South China Sea 20N 120E (same as in Farris and Wimbush, 1996) indicating the seasonal variation of the northeast monsoon (upper panel) . The seasonal variation of the Kuroshio penetrating loop current latitude indicating the two different (southern and northern) pathways of penetration (middle panel). Examples of the flow patterns corresponding to the southern pathway (1999/06/20, lower left) and northern pathway (1998/12/15, lower right). The results are based on an analysis of the NLOM SSH data during the hindcast run for the period 1993-2000.

RELATED PROJECTS

We also studied a similar phenomenon of a boundary current leaping across the gap in the context of a shelf-break current in the Georges Bank area. It was found that the loop current penetrations are caused by weakening of the shelf-break front as expressed by its density difference (Cho *et al*., 2002).

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